KxGenerator

version 2.5

User's manual

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1. INTRODUCTION

The KxGenerator application version 2.5 has been designed to enable the user to calculate the features of the horizontal co-operation of any subsoil with pile foundation according to the M. Kosecki's proposal – *'Statyka ustrojów palowych, Zasady obliczania konstrukcji palowych metodą uogólnioną',* Szczecin 2006.

2. TERMINOLOGY

The following terms have been used in the further part of the manual:

program	–	KxGenerator version 2.5
general method	–	*'Statyka ustrojów palowych, Zasady obliczania konstrukcji palowych metodą uogólnioną. Kosecki M.',* Szczecin 2006.
comments to the method	–	*'Obliczenia statyczne fundamentów palowych, Seminarium – Zagadnienia posadowień na fundamentach palowych'.* Krasiński A., Gdańsk 25 czerwca 2004.

3. APPLICATION USAGE

The program has been designed to calculate the horizontal stiffness of soil together with the influence of foundation piles. The program generates a structure of horizontal spring supports arranged along the axis of each pile, and allows making calculations for the pile foundation. These calculations include the natural influence of both the springy and plastic co-operation between piles and soil.

The program performs calculations in accordance with the M. Kosecki's general method and A. Krasiński's comments to the method.

The program calculates the evenly distributed horizontal stiffness of soil and maximum horizontal soil resistance. The pile division into elements of any length allows determining the value of the spring supports in particular nodes as well as their correspondent maximum horizontal soil responses.

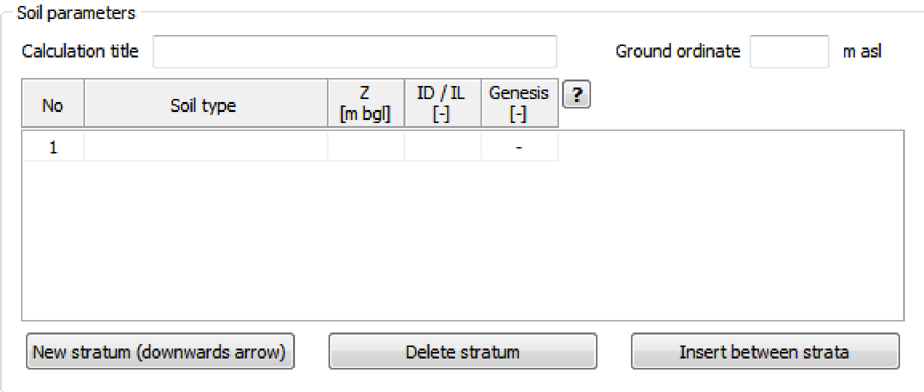
Once the horizontal spring supports is determined further calculations of the piles together with the foundation (plate, bench and footing) as well as other structural elements of the building are possible.

The program includes author's **'the scheme of pile foundation'** which enables the user to calculate the horizontal stiffness of piles for several directions of the horizontal load, and different pile spacing.

The calculation results are being presented graphically as a configuration of the module of horizontal stiffness of soil and maximum horizontal soil resistance including depth. Additionally the results are being presented as numerical values in particular nodes located along pile axis.

4. DATA ENTRY – DATA TAB

Soil parameters



Calculation title – the title describing the analyzed soil profile/project

Ground ordinate – the ordinate of the existent ground level presented in meters above sea level. Once the ordinate of the ground is specified, the soil profile created in AutoCad will include additional elevation information i.e. above mean sea level.

The table of soil strata:

No – the number of the actual soil strata (this column is generated automatically)

Soil type – the proper soil stratum should be chosen from the proved list by clicking the mouse (do not type the name)

Z [m bgl] – the ordinate of the bottom of soil stratum (in metres below ground level)

ID/IL [-] – the density index/ liquidity index of soil stratum

Genesis [-] – the genesis of cohesive soil (A, B, C, D), for non-cohesive soil '–'
Symbols for cohesive soils according to PN-81/B-03020:

A – consolidated cohesive moraine soils,

B – other cohesive soils and non-consolidated cohesive moraine soils,

C – other non-consolidated cohesive soils,

D – clay, regardless of geological genesis.

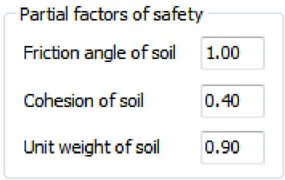
The following buttons should be used when editing the table regarding soil strata:

New stratum (downwards arrow) – creates another stratum, click the downwards arrow on the keyboard ⇩

Delete stratum – deletes the current stratum

Insert between strata – inserts additional stratum between existing ones – this option should not be used fro creating new stratum

Partial factors of safety



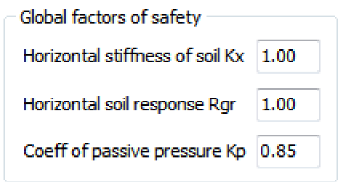
Partial factors of safety have been determined for the following physical features of soil: friction angle, cohesion and unit weight of soil. There is a possibility to modify default values of each individual factor.

Partial factor of safety for friction angle of soil ϕ – the default value of the factor is 1.00.

Partial factor of safety for cohesion soil c – the default value of the factor is 0.40.

Partial factor of safety for unit weight of soil γ – the default value of the factor is 0.90.

Global factors of safety



The following global factors of safety for: horizontal stiffness of soil, maximum horizontal soil response and passive pressure have been used:

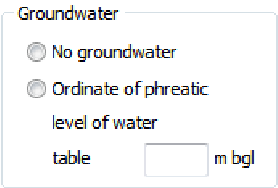
Global factor of horizontal stiffness of soil Kx – the default value of the factor is 1.00.

Global factor of maximum horizontal soil response Rgr – the default value of the factor is 1.00.

Global factor of horizontal passive pressure Kp embracing the simplification that the flat slide plane is adopted η – the default value of the factor is 0.85.

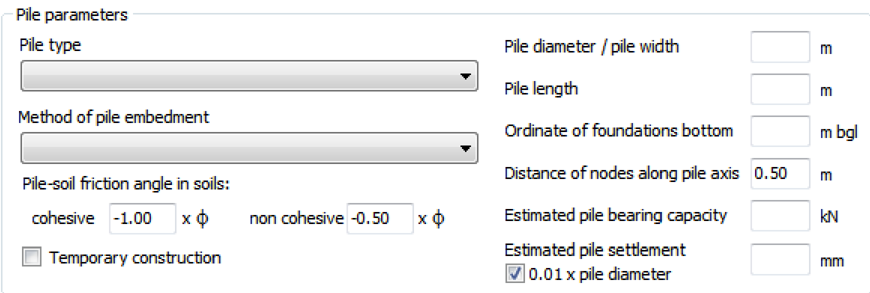
There is a possibility to modify default values of each individual factor.

Groundwater



If the groundwater emerges it is necessary to provide the ordinate of the phreatic water table. It follows that for the soil stratum occurring below the phreatic water table, the unit weight of submerged soil γ' shall be applied.

Pile parameters



Type of pile – the type of the pile must be defined. The program allows choosing the following foundation piles from the list:

- user's pile – all methods of pile embedment are available
- precast concrete pile
- steel hollow section pile, closed base
- steel hollow section pile, open base
- rotary bored pile
- rotary bored pile, base-injected
- Vibro
- Vibrex
- Fundex
- Franki
- CFA
- Atlas
- Omega
- Tubex
- small diameter, grout or concrete injected

Method of pile embedment – the method of pile embedment should be defined in case one chose the following positions from the above list: user pile, precast pile (concrete, made from steel sections) or bored pile. The method of pile embedment for the remaining piles has been

automatically defined by the proper type of pile (e.g. pile CFA – bored, ATLAS – driven, etc.). The program allows choosing the following methods of pile embedment of the foundation piles:

- driven pile
- vibration driven pile
- water jet driven (last 1m hammer driven)
- cast-in-place, support fluid
- cast-in-place, casing extracted
- cast-in-place, casing left in place
- cast-in-place, casing rotary-extracted
- cast-in-place, rotary-suction with water-jet

The value of the pile-soil friction angle – define the friction angle towards the pile and soil δ with reference to the soil friction angle ϕ. There is a possibility to modify the default coefficient values of cohesive and non-cohesive soil.

Temporary construction – define the use of the pile foundation. If the foundation is a temporary construction, the default value of the coefficient for long-lasting or cyclic loads effect φ is 1.00. Otherwise the coefficient φ is applied according to the Kosecki's recommendation.

Pile diameter / pile width – for piles with a circular cross section the pile diameter should be provided, for piles with a square cross section the breadth of the pile side (width) should be defined.

Pile length – define the pile length measured from the foundation bottom to the pile base.

Ordinate of foundation bottom – define the ordinate of foundation bottom.

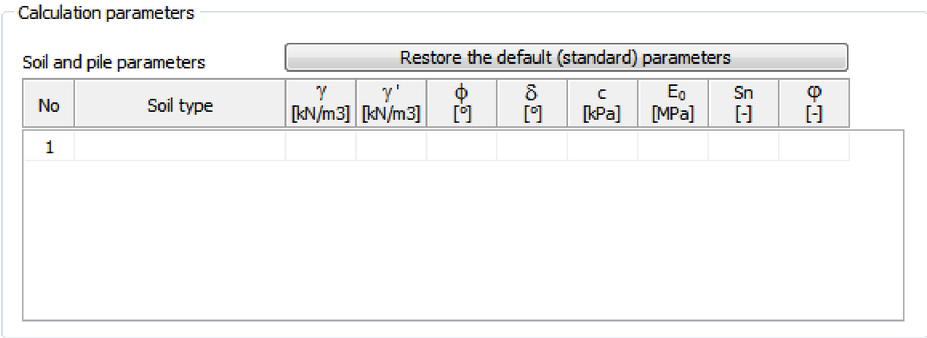
Node spacing along pile axis – define the distance between adjoining nodes of the spring supports and the maximum horizontal soil response that shall be placed along the pile axis. The default value of the node spacing is 0.50m.

Estimated pile bearing capacity – define estimated (approximated) pile bearing capacity.

Estimated pile settlement – define estimated (approximated) pile settlement. The program automatically generates approximated pile settlement as product of 0.01 x D (D – pile diameter / pile width). The user can freely modify default value of pile settlement.

5. CALCULATION PARAMETERS – CALCULATION TAB

Soil and pile parameters – once the following parameters have been defined in the tab 'Data': the soil type, density/liquidity index (including the genesis of cohesive soil) as well as the type and method of pile embedment, the program automatically generates subsequent parameters: (γ, γ', ϕ, δ, c, E_0 in accordance with PN-81/B-03020 while S_n and φ compliant with the general method). The user can **freely modify** all standardized values of the parameters. Once the parameter has been changed there is a possibility to restore the default (standard) value.



No – reference number of the soil stratum

Soil type – type of the soil

γ [kN/m3] – unit weight of soil

γ' [kN/m3] – effective unit weight of soil (unit weight of submerged soil)

ϕ [°] – friction angle of soil

δ [°] – pile-soil friction angle

c [kPa] – cohesion of soil

E_0 [MPa] – initial soil deformation modulus

$$E_0 = \frac{(1+\nu)\cdot(1-2\nu)}{1-\nu}\cdot M_0$$

ν – Poisson's ratio

M_0 – oedometer modulus (E_{0ed})

Sn [-] – coefficient for the method of pile embedment (soil structure disturbance when embedding the pile)

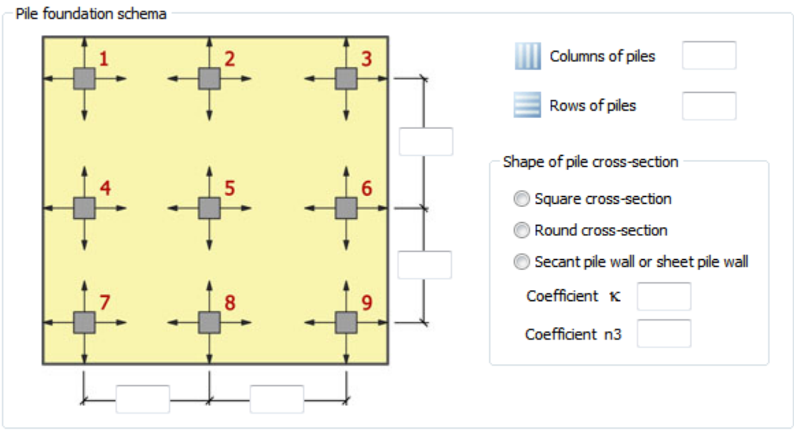
φ [-] – coefficient for long-lasting or cyclic loads effect

Scheme of the pile foundation

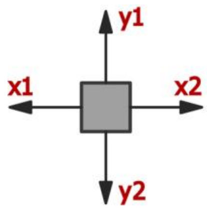
The program includes an innovative and original scheme of pile foundation which allows calculating the stiffness of pile for several directions of the horizontal load and for different pile spacing. The scheme of pile foundation is used to generate the **authentic pile arrangement** in the designed

foundation. The so called representative scheme consists of 9 characteristic piles numbered from 1 to 9. Each number stands for a specific pile: corner, edge and central (look pts. 7.1 ÷ 7.4). The actual design of pile foundation may include more or fewer piles than 9.

The program does calculation for 4 directions of the horizontal load as well as for each pile separately (from 1-9), which felicitates the process of designing the foundation.



Symbols of the 4 possible horizontal load directions



The description of piles in the scheme of the pile foundation:

- **Pile # 5**

  The pile is located in the inner row and the inner column of piles. The pile No. 5 is surrounded by piles from the adjoining rows and adjoining columns – the central pile of the pile group.

- **Piles # 2 and 8**

  The piles are located in the inner column and the outermost row of piles. The piles No. 2 and 8 are surrounded by piles from adjoining columns and are located in the outermost row of the pile group.

- **Piles # 4 and 6**

  The piles are located in the inner row and the outermost column of piles. The piles No. 4 and 6 are surrounded by piles from adjoining rows and are located in the outermost column of the pile group.

- **Piles # 1, 3, 7, 9**

  The piles are located in the outermost row and the outermost column of piles. The piles No. 1, 3, 7 i 9 are not surrounded by any piles of adjoining rows or any adjoining columns of the pile group – corner piles.

In accordance with the general method the horizontal stiffness of soil **Kx** and the maximum horizontal soil response **Rgr** within single foundation may differ from one another depending on the distance from adjoining piles. Coefficients **n1** and **n2** comprise the information as to the impact of the pile number and spacing.

The program allows the user to freely change the coefficients depending on the location of the pile in the foundation – e.g. the pile may be located in the first or farther rows, the pile may be located in the outermost or inner row. The instruction how to define coefficients **n1** and **n2** is presented in pt. 6.

The scheme of pile foundation presents values of the coefficients **n1·n2** product for all four directions of the horizontal load, and separately for each pile. The product of the **n1·n2** coefficients (in line with formulas for Kx and Rgr described in pt. 6) reduces the value of the stiffness and maximum horizontal soil response depending on the adjoining pile spacing and direction of the horizontal load impact.

6. RULES FOR CALCULATING THE STIFFNESS OF THE PILE AND MAXIMUM HORIZONTAL SOIL RESPONSE

6.1 STIFFNESS OF PILE

The calculation of the stiffness of the pile requires indicating the value of the module of horizontal stiffness of soil Kx. The program additionally defines the values of the springy horizontal support in nodes arranged along the pile axis. Further calculation of the pile foundation applies programs that are based on bars' models – modelling of the subsoil with the use of spring supports.

The value of the module of horizontal stiffness of soil **Kx**

$$K_X = n_0 \cdot n_1 \cdot n_2 \cdot S_n \cdot \kappa \cdot \varphi \cdot E_0$$

6.2 MAXIMUM HORIZONTAL SOIL RESPONSE

In this calculation the value of the maximum horizontal soil resistance needs to be specified. Additionally the program indicates the value of the maximum horizontal soil response in nodes arranged along the pile axis. The mentioned calculations allow for a simulation of soil liquidity once the maximum horizontal soil resistance is exceeded.

The value of the maximum horizontal soil response **Qr**

$$Q_r = m_1 \cdot S_n \cdot n_1 \cdot n_2 \cdot n_3 \cdot D_0 \cdot \left(\sigma' K_{ph}' + c \cdot \sqrt{K_{ph}'}\right)$$

where:

- **n_0** – corrective coefficient for the effect of pile diameter
- **n_1** – coefficient for the spacing of piles in a group arranged in the plane perpendicular to the direction of the horizontal load
- **n_2** – coefficient for the spacing of piles in a group arranged in the plane parallel to the direction of the horizontal load
- **n_3** – coefficient reflecting the spatial feature of the effect of the horizontal soil resistance, it is conditioned upon the shape of the pile cross-section
- **Sn** – coefficient for the method of the pile embedment (the disturbance of the soil structure during the pile embedment)
- **κ** – coefficient for the spatial dimension of the soil response, it is conditioned upon the shape of the pile cross-section
- **φ** – coefficient for the long-lasting or cyclic loads effect

E_0 – initial deformation modulus

$$E_0 = \frac{(1+\nu)\cdot(1-2\nu)}{1-\nu}\cdot M_0$$

ν – Poisson's ratio

M_0 – oedometer modulus (E_{0ed})

m_1 – corrective coefficient comprising piles' co-operation in a group of piles

D_0 – substitute pile diameter

σ' – horizontal effective stress in soil

Kph' – coefficient for horizontal passive pressure

c – cohesion of soil

7. VALUE OF THE n1 AND n2 COEFFICIENTS DEPENDING ON THE LOCATION OF THE PILE IN FOUNDATION

In their simplest form formulas for the **n1** and **n2** coefficients, in accordance with the general method, equal:

Coefficient **n1**:

$$n_1 = 0.2 \cdot \frac{R_1}{D} + 0.4 \leq 1.0$$

Coefficient **n2**:

$$n_2 = \beta + \frac{(1-\beta)\cdot(R_2 - D)}{1.8\cdot(1.5\cdot D + 0.5)} \leq 1.0 \qquad \text{for } D<1.0\text{m}$$

$$n_2 = \beta + \frac{(1-\beta)\cdot(R_2 - D)}{1.8\cdot(D + 1.0)} \leq 1.0 \qquad \text{for } D\geq 1.0\text{m}$$

where:

D – pile diameter or pile width [m];

R_1 – axial pile spacing in the plane perpendicular to direction of the horizontal load, [m];

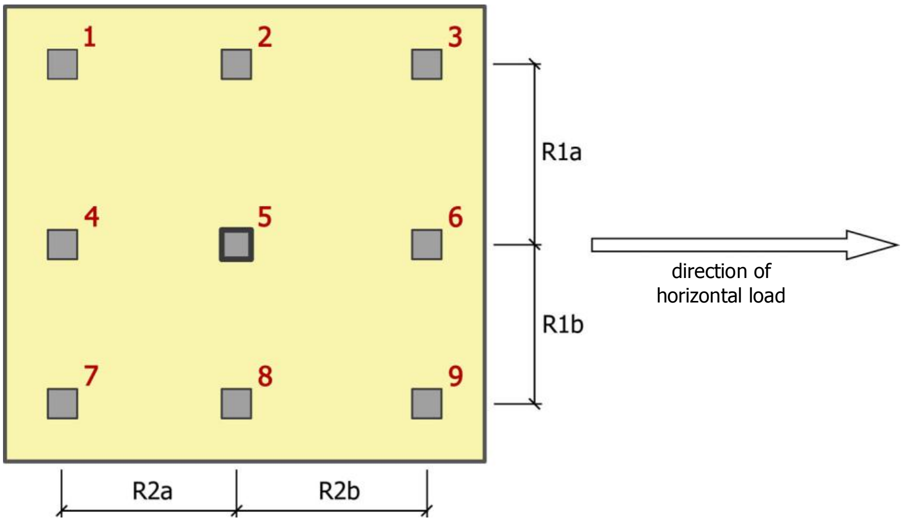
R_2 – axial pile spacing in the plane parallel to direction of the horizontal load, [m];

B – coefficient dependent on the number of piles in a row parallel to direction of the horizontal load, [-] (β = 1.0 for one row of piles, β = 0.6 for two rows of piles, β = 0.5 for three rows of piles, β = 0.45 for four or more rows of piles).

The scheme of pile foundation includes an option that allows modifying the stiffness of piles depending on the location of the pile in foundation – different values of **n1** and **n2** coefficients are available. The description of the proper way of defining the coefficient values for specific piles is described in the further part of the manual.

7.1 PILE LOCATED IN THE INNER ROW AND INNER COLUMN OF PILES

It is the pile No. 5 in the scheme of pile foundation, which is surrounded by piles from the adjoining rows and columns – so-called the central pile of the pile group.



In its simplest form the formula for **n1** coefficient equals:

$$n_1 = 0.2 \cdot \frac{R_1}{D} + 0.4 \leq 1.0$$

The central pile of the pile group (No. 5 presented in the above picture) is surrounded by adjoining piles and their axial spacing in the plane perpendicular to the direction of the horizontal load is **R1a** and **R1b**. The program allows entering different pile spacing values (**R1a≠R1b**), therefore the **n1** coefficient for pile No. 5 is being calculated as a mean value in accordance with the following formula:

$$n_{1,pile5} = \frac{n_1(R1a) + n_1(R1b)}{2} = \frac{\left(0.2 \cdot \frac{R1a}{D} + 0.4\right) + \left(0.2 \cdot \frac{R1b}{D} + 0.4\right)}{2} \leq 1.0$$

In its simplest form the formula for coefficient **n2** equals:

$$n_2 = \beta + \frac{(1-\beta)\cdot(R_2 - D)}{1.8\cdot(1.5\cdot D + 0.5)} \leq 1.0 \qquad \text{for } D<1.0\text{m}$$

$$n_2 = \beta + \frac{(1-\beta)\cdot(R_2 - D)}{1.8\cdot(D + 1.0)} \leq 1.0 \qquad \text{for } D\geq 1.0\text{m}$$

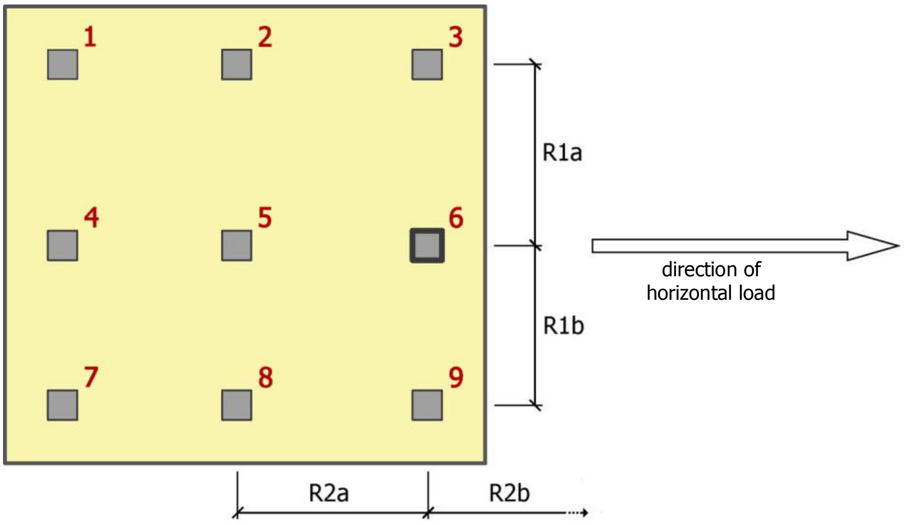
As presented in the above picture the central pile of the pile group (No.5) is surrounded by adjoining piles, which pile spacing in the plane parallel to direction of the horizontal load effect is **R2a** and **R2b**. The program calculates the value of **n2** coefficient on the basis of the axial spacing of piles that limit the stiffness of the pile – i.e. piles located in front of the discussed pile; in accordance with the direction of the horizontal load. Therefore, the calculation of the **n2** coefficient for the pile No. 5, including the direction of the horizontal load and depending on the **R2b** spacing is performed in accordance with the following formulas:

$$n_{2,pile5} = \beta + \frac{(1-\beta)\cdot(R2b - D)}{1.8\cdot(1.5\cdot D + 0.5)} \leq 1.0 \qquad \text{for } D<1.0\text{m}$$

$$n_{2,pile5} = \beta + \frac{(1-\beta)\cdot(R2b - D)}{1.8\cdot(D + 1.0)} \leq 1.0 \qquad \text{for } D\geq 1.0\text{m}$$

7.2 PILE LOCATED INSIDE THE OUTERMOST ROW OR OUTERMOST COLUMN OF PILES

In the scheme of pile foundation these are piles No. 2, 4, 6 and 8. They are surrounded by piles of the adjoining rows or columns – so-called the edge piles of the pile group. The values of coefficients **n1** and **n2** for the pile No. 6 are presented below (the same rule applies as to the calculation of coefficients for piles No. 2, 4 and 8).



In its simplest form the formula for **n1** coefficient equals:

$$n_1 = 0.2 \cdot \frac{R_1}{D} + 0.4 \le 1.0$$

The edge pile of the pile group (No. 6), as presented in the picture, is surrounded by adjoining piles and their axial pile spacing in the plane perpendicular to the direction of the horizontal load is **R1a** and **R1b**. The program allows entering different values for the spacing of adjoining piles (**R1a≠R1b**); therefore the **n1** coefficient for the edge pile No. 6 is being calculated in the same way as for the central pile No. 5 as a mean value in accordance with the following formula:

$$n_{1,pile6} = \frac{n_1(R1a) + n_1(R1b)}{2} = \frac{\left(0.2 \cdot \frac{R1a}{D} + 0.4\right) + \left(0.2 \cdot \frac{R1b}{D} + 0.4\right)}{2} \le 1.0$$

In its simplest form the formula for **n2** coefficient equals:

$$n_2 = \beta + \frac{(1-\beta)\cdot(R_2 - D)}{1.8 \cdot (1.5 \cdot D + 0.5)} \le 1.0 \qquad \text{for } D<1.0\text{m}$$

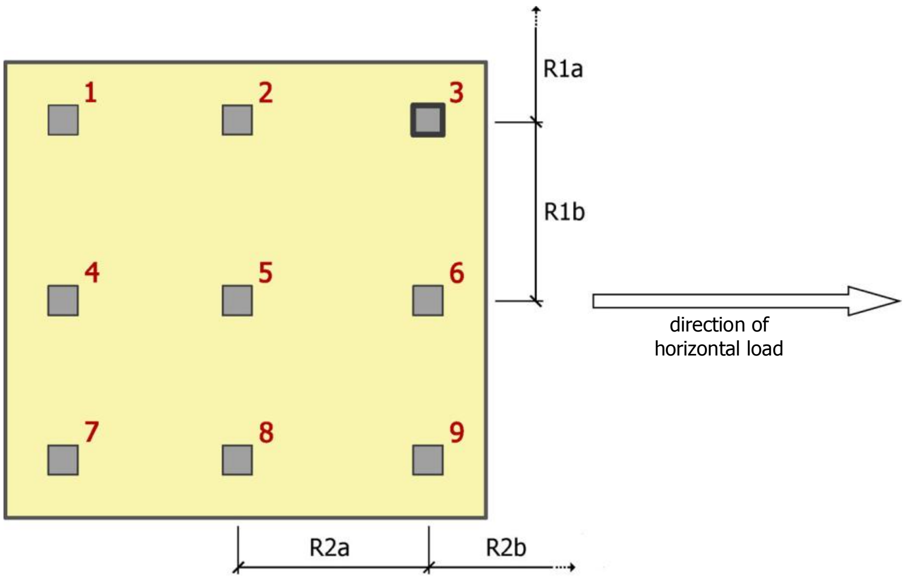
$$n_2 = \beta + \frac{(1-\beta)\cdot(R_2 - D)}{1.8 \cdot (D + 1.0)} \le 1.0 \qquad \text{for } D\ge1.0\text{m}$$

In the program the calculation of the value of the **n2** coefficient is dependent on the axial spacing of piles that limit the stiffness of pile – i.e. the piles located in front of the analyzed pile; in accordance

with the direction of the horizontal load. As in the example for the pile No. 6, for the direction of the horizontal load there is no reduction in stiffness with regard to axial pile spacing **R2b**. Therefore the value of the **n2** coefficient for the edge pile No. 6 is **1.0**.

7.3 PILE LOCATED IN THE OUTERMOST ROW AND OUTERMOST COLUMN OF PILES

In the scheme of pile foundation these are piles No. 1, 3, 7 and 9. They are surrounded by adjoining piles from one side only – so-called corner piles of the pile group. The values of coefficients **n1** and **n2** for the corner pile No. 3 are presented below (the same rule applies for the calculation of coefficients **n1** and **n2** for corner piles No. 1, 7 and 9).



In its simplest form the formula for **n1** coefficient equals:

$$n_1 = 0.2 \cdot \frac{R_1}{D} + 0.4 \leq 1.0$$

The corner pile of the pile group (No. 3), as presented in the above picture, in the plane perpendicular to directions of the horizontal load is surrounded by piles from one side only and the axial pile spacing equals **R1b**. There are no adjoining piles on the other side of the corner pile, so its stiffness is limited from one side only. Accordingly the calculation for the **n1** coefficient for the corner pile No. 3 accounts for greater stiffness. The calculation result is presented as a mean value in accordance with the following formula:

$$n_{1,pile3} = \frac{n_1(R1b) + 1.0}{2} = \frac{\left(0.2 \cdot \frac{R1a}{D} + 0.4\right) + 1.0}{2} \leq 1.0$$

In its simplest form the formula for **n2** coefficient equals:

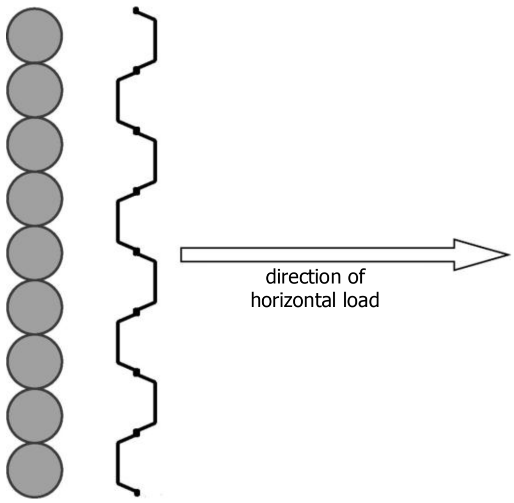
$$n_2 = \beta + \frac{(1-\beta)\cdot(R_2 - D)}{1.8\cdot(1.5\cdot D + 0.5)} \leq 1.0 \quad \text{for } D<1.0\text{m}$$

$$n_2 = \beta + \frac{(1-\beta)\cdot(R_2 - D)}{1.8\cdot(D + 1.0)} \leq 1.0 \quad \text{for } D\geq 1.0\text{m}$$

In the program the calculation of the value of the **n2** coefficient is dependent on the axial spacing of piles that limit the stiffness of the pile – i.e. the piles located in front of the analyzed pile; in accordance with the direction of the horizontal load. As in the example for the corner pile No. 3, for the direction of the horizontal load there is no reduction in stiffness with regard to the axial pile spacing **R2b**. Therefore the value of the **n2** coefficient for the corner pile No. 3 is exactly the same as for the edge pile No.6 i.e. **1.0**.

7.4 SECANT PILE WALL OR SHEET PILE WALL

The adjoining elements of the secant pile wall and sheet pile wall are placed very close to one another – there is no distance between them. The axial pile spacing (in the secant pile wall) and sheet pile spacing (in the sheet pile wall) in the plane perpendicular to the direction of the horizontal load equals the breadth of a single element.



In its simplest form the formula for **n1** coefficient equals:

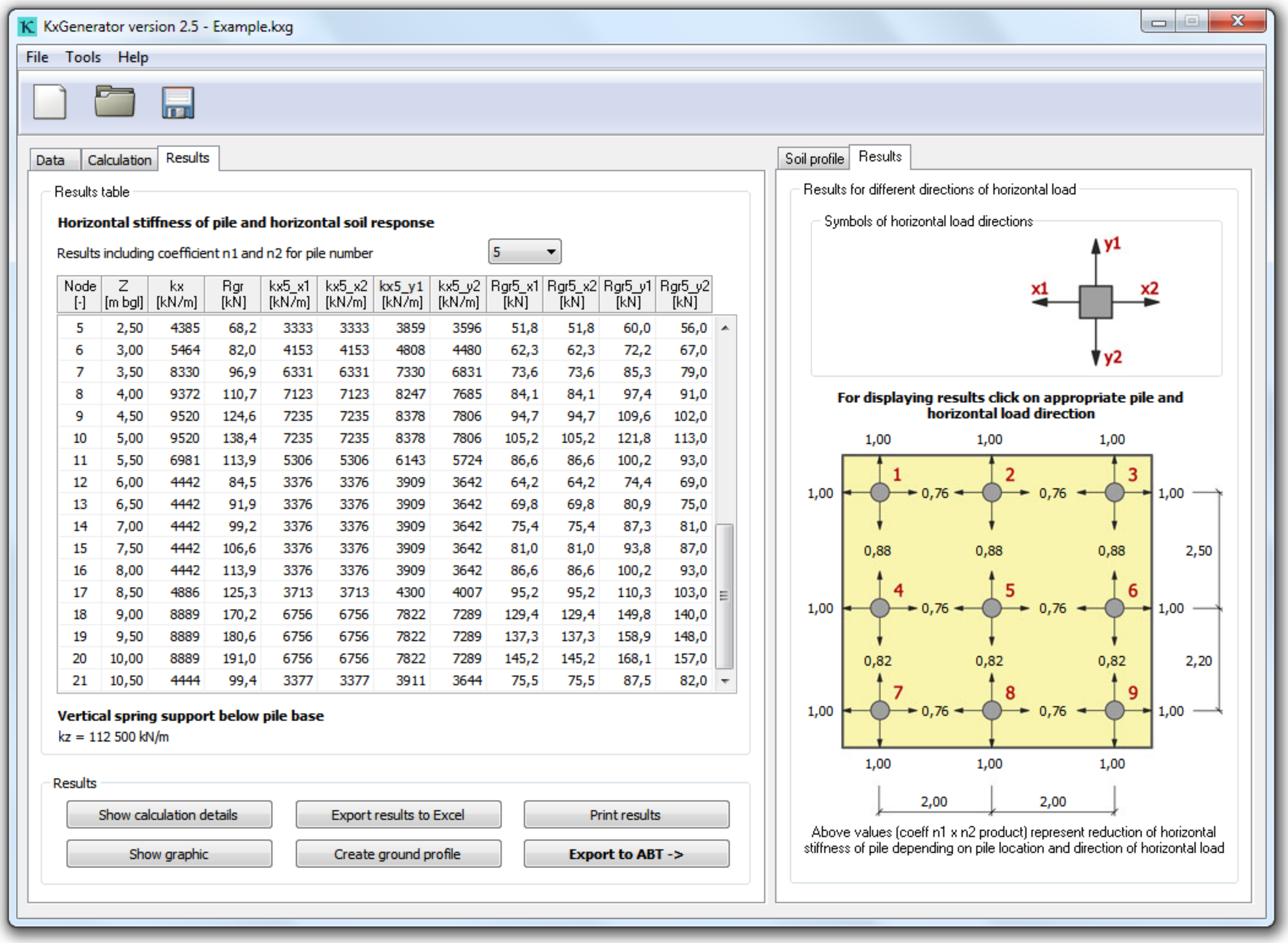
$$n_1 = 0.2\cdot\frac{R_1}{D} + 0.4 \leq 1.0$$

The MES analysis showed that for the running construction there is a reduction in horizontal stiffness with regard to the horizontal stiffness of a single element. The axial spacing of elements (piles or sheet piles) for the running construction in the plane perpendicular to the direction of the horizontal load - **R1 = D**. As in the program the default coefficient **n1** = **0.20 + 0.40** = **0.60**, accordingly the **n1·n2** product is **0.60**.

8. CALCULATION RESULTS – RESULTS TAB

The results of the performed calculations are shown in two tabs **Results**. The data is presented in a table that includes the values for horizontal stiffness of pile kx and maximum horizontal soil response Rgr in particular nodes for all piles of the scheme of pile foundation.

Table of results – results of the performed calculations



Node [-]	Z [m bgl]	kx [kN/m]	Rgr [kN]	kx5_x1 [kN/m]	kx5_x2 [kN/m]	kx5_y1 [kN/m]	kx5_y2 [kN/m]	Rgr5_x1 [kN]	Rgr5_x2 [kN]	Rgr5_y1 [kN]	Rgr5_y2 [kN]
5	2,50	4385	68,2	3333	3333	3859	3596	51,8	51,8	60,0	56,0
6	3,00	5464	82,0	4153	4153	4808	4480	62,3	62,3	72,2	67,0
7	3,50	8330	96,9	6331	6331	7330	6831	73,6	73,6	85,3	79,0
8	4,00	9372	110,7	7123	7123	8247	7685	84,1	84,1	97,4	91,0
9	4,50	9520	124,6	7235	7235	8378	7806	94,7	94,7	109,6	102,0
10	5,00	9520	138,4	7235	7235	8378	7806	105,2	105,2	121,8	113,0
11	5,50	6981	113,9	5306	5306	6143	5724	86,6	86,6	100,2	93,0
12	6,00	4442	84,5	3376	3376	3909	3642	64,2	64,2	74,4	69,0
13	6,50	4442	91,9	3376	3376	3909	3642	69,8	69,8	80,9	75,0
14	7,00	4442	99,2	3376	3376	3909	3642	75,4	75,4	87,3	81,0
15	7,50	4442	106,6	3376	3376	3909	3642	81,0	81,0	93,8	87,0
16	8,00	4442	113,9	3376	3376	3909	3642	86,6	86,6	100,2	93,0
17	8,50	4886	125,3	3713	3713	4300	4007	95,2	95,2	110,3	103,0
18	9,00	8889	170,2	6756	6756	7822	7289	129,4	129,4	149,8	140,0
19	9,50	8889	180,6	6756	6756	7822	7289	137,3	137,3	158,9	148,0
20	10,00	8889	191,0	6756	6756	7822	7289	145,2	145,2	168,1	157,0
21	10,50	4444	99,4	3377	3377	3911	3644	75,5	75,5	87,5	82,0

Table of results:

Node No – node number

Z [m bgl] – ordinate of the node below ground level

kx [kN/m] – basic value of the springy support excluding the reduction in stiffness on account of the arrangement and spacing of piles – the product of the coefficients n1·n2=1.00

Rgr [kN] – basic value of the maximum horizontal soil response excluding the reduction in stiffness on account of the arrangement and spacing of piles – the product of the coefficients n1·n2=1.00

kx5_x1 [kN/m] – value of the spring support of the pile No. 5 for direction $\mathbf{x_1}$ of the horizontal load, including the probable reduction in stiffness on account of the number and spacing of piles

kx5_x2 [kN/m] – value of the spring support of the pile No. 5 for direction $\mathbf{x_2}$ of the horizontal load, including the probable reduction in stiffness on account of the number and spacing of piles

kx5_y1 [kN/m] – value of the spring support of the pile No. 5 for direction $\mathbf{y_1}$ of the horizontal load, including the probable reduction in stiffness on account of the number and spacing of piles

kx5_y2 [kN/m] – value of the spring support of the pile No. 5 for direction $\mathbf{y_2}$ of the horizontal load, including the probable reduction in stiffness on account of the number and spacing of piles

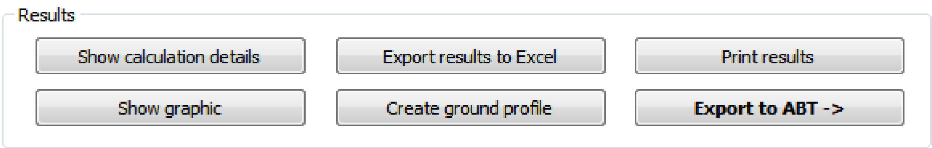
Rgr5_x1 [kN/m] – value of the maximum horizontal soil response of the pile No. 5 for direction $\mathbf{x_1}$ of the horizontal load, including the probable reduction in stiffness on account of the number and spacing of piles

Rgr5_x2 [kN/m] – value of the maximum horizontal soil response of the pile No. 5 for direction $\mathbf{x_2}$ of the horizontal load, including the probable reduction in stiffness on account of the number and spacing of piles

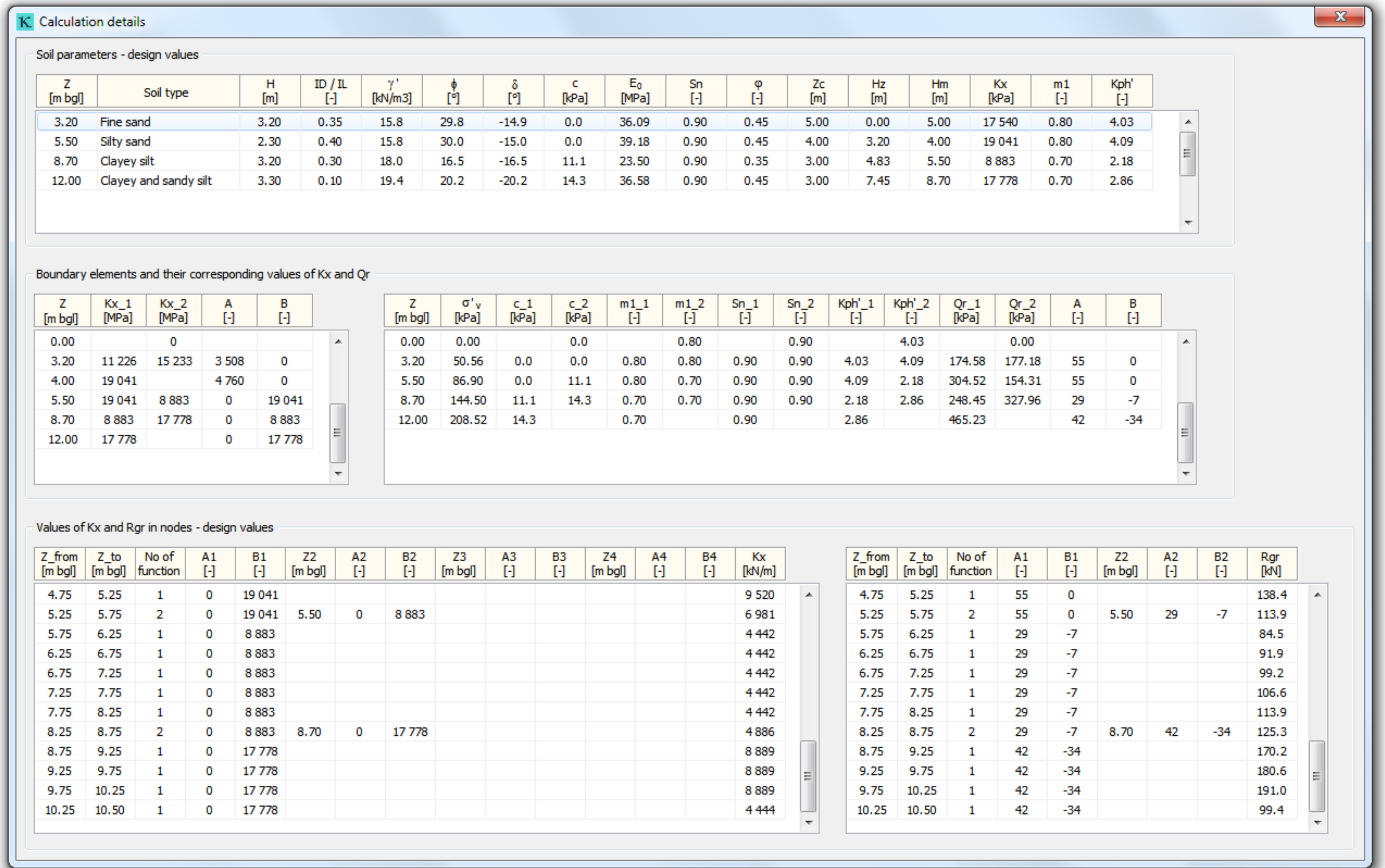
Rgr5_y1 [kN/m] – value of the maximum horizontal soil response of the pile No. 5 for direction $\mathbf{y_1}$ of the horizontal load, including the probable reduction in stiffness on account of the number and spacing of piles

Rgr5_y2 [kN/m] – value of the maximum horizontal soil response of the pile No. 5 for direction $\mathbf{y_2}$ of the horizontal load, including the probable reduction in stiffness on account of the number and spacing of piles

Results



Click on the button **Show calculation details** in order to see details of the performed calculations.



Soil parameters - design values

Z [m bgl]	Soil type	H [m]	ID / IL [-]	γ' [kN/m3]	ϕ [°]	δ [°]	c [kPa]	E_0 [MPa]	Sn [-]	φ [-]	Zc [m]	Hz [m]	Hm [m]	Kx [kPa]	m1 [-]	Kph' [-]
3.20	Fine sand	3.20	0.35	15.8	29.8	-14.9	0.0	36.09	0.90	0.45	5.00	0.00	5.00	17 540	0.80	4.03
5.50	Silty sand	2.30	0.40	15.8	30.0	-15.0	0.0	39.18	0.90	0.45	4.00	3.20	4.00	19 041	0.80	4.09
8.70	Clayey silt	3.20	0.30	18.0	16.5	-16.5	11.1	23.50	0.90	0.35	3.00	4.83	5.50	8 883	0.70	2.18
12.00	Clayey and sandy silt	3.30	0.10	19.4	20.2	-20.2	14.3	36.58	0.90	0.45	3.00	7.45	8.70	17 778	0.70	2.86

Boundary elements and their corresponding values of Kx and Qr

Z [m bgl]	Kx_1 [MPa]	Kx_2 [MPa]	A [-]	B [-]
0.00		0		
3.20	11 226	15 233	3 508	0
4.00	19 041		4 760	0
5.50	19 041	8 883	0	19 041
8.70	8 883	17 778	0	8 883
12.00	17 778		0	17 778

Z [m bgl]	σ'v [kPa]	c_1 [kPa]	c_2 [kPa]	m1_1 [-]	m1_2 [-]	Sn_1 [-]	Sn_2 [-]	Kph'_1 [-]	Kph'_2 [-]	Qr_1 [kPa]	Qr_2 [kPa]	A [-]	B [-]
0.00	0.00		0.0		0.80		0.90		4.03		0.00		
3.20	50.56	0.0	0.0	0.80	0.80	0.90	0.90	4.03	4.09	174.58	177.18	55	0
5.50	86.90	0.0	11.1	0.80	0.70	0.90	0.90	4.09	2.18	304.52	154.31	55	0
8.70	144.50	11.1	14.3	0.70	0.70	0.90	0.90	2.18	2.86	248.45	327.96	29	-7
12.00	208.52	14.3		0.70		0.90		2.86		465.23		42	-34

Values of Kx and Rgr in nodes - design values

Z_from [m bgl]	Z_to [m bgl]	No of function	A1 [-]	B1 [-]	Z2 [m bgl]	A2 [-]	B2 [-]	Z3 [m bgl]	A3 [-]	B3 [-]	Z4 [m bgl]	A4 [-]	B4 [-]	Kx [kN/m]
4.75	5.25	1	0	19 041										9 520
5.25	5.75	2	0	19 041	5.50	0	8 883							6 981
5.75	6.25	1	0	8 883										4 442
6.25	6.75	1	0	8 883										4 442
6.75	7.25	1	0	8 883										4 442
7.25	7.75	1	0	8 883										4 442
7.75	8.25	1	0	8 883										4 442
8.25	8.75	2	0	8 883	8.70	0	17 778							4 886
8.75	9.25	1	0	17 778										8 889
9.25	9.75	1	0	17 778										8 889
9.75	10.25	1	0	17 778										8 889
10.25	10.50	1	0	17 778										4 444

Z_from [m bgl]	Z_to [m bgl]	No of function	A1 [-]	B1 [-]	Z2 [m bgl]	A2 [-]	B2 [-]	Rgr [kN]
4.75	5.25	1	55	0				138.4
5.25	5.75	2	55	0	5.50	29	-7	113.9
5.75	6.25	1	29	-7				84.5
6.25	6.75	1	29	-7				91.9
6.75	7.25	1	29	-7				99.2
7.25	7.75	1	29	-7				106.6
7.75	8.25	1	29	-7				113.9
8.25	8.75	2	29	-7	8.70	42	-34	125.3
8.75	9.25	1	42	-34				170.2
9.25	9.75	1	42	-34				180.6
9.75	10.25	1	42	-34				191.0
10.25	10.50	1	42	-34				99.4

Table **Soil parameters**

Z [m bgl] – ordinate of the soil stratum bottom

Soil type – type of the soil stratum

H [m] – thickness of the soil stratum

ID / IL – soil density index / soil liquidity index

γ' [kN/m3] – effective unit weight of soil (unit weight of submerged soil)

ϕ [°] – friction angle of soil

δ [°] – pile-soil friction angle

c [kPa] – cohesion of soil

E0 [MPa] – initial deformation modulus

$$E_0 = \frac{(1+\nu)\cdot(1-2\nu)}{1-\nu}\cdot M_0$$

ν – Poisson's ratio

M_0 – oedometer modulus (E_{0ed})

Sn [-] – coefficient for method of pile embedment

φ [-] – coefficient for the long-lasting or cyclic loads effect

Zc [m bgl] – critical height of soil stratum – the thickness of soil stratum when the maximum horizontal soil stiffness is mobilized

Hz [m bgl] – equivalent height of soil stratum

Hm [m bgl] – depth of mobilisation the maximum horizontal soil stiffness

Kx [kPa] – module of horizontal stiffness of soil stratum

m1 [-] – corrective coefficient equal 0.7 of cohesive soil and 0.8 of non-cohesive soil

Kph' [-] – coefficient for passive pressure

Table **Boundary elements and their corresponding Kx values**

Z [m bgl] – ordinate of the soil stratum bottom

Kx_1 [kPa] – module of horizontal stiffness of soil for stratum with bottom on the ordinate Z

Kx_2 [kPa] – module of horizontal stiffness of soil for stratum with top on the ordinate Z

A [-] – slope of linear function y=Ax + B

B [-] – y-intercept of linear function y=Ax + B

Table **Boundary elements and their corresponding Qr values**

Z [m bgl] – ordinate of the soil stratum bottom

σ'_v [kPa] – horizontal effective stress in soil

c_1 [kPa] – cohesion of soil for stratum with bottom on the ordinate Z

c_2 [kPa] – cohesion of soil for stratum with top on the ordinate Z

m1 [-] – corrective coefficient for stratum with bottom on the ordinate Z

m2 [-] – corrective coefficient for stratum with top on the ordinate Z

Sn_1 [-] – coefficient for the impact of the method of pile embedment for stratum with bottom on the ordinate Z

Sn_2 [-] – coefficient for the impact of the method of pile embedment for stratum with top on the ordinate Z

Kph'_1 [-] – coefficient for passive pressure for stratum with bottom on the ordinate Z

Kph'_2 [-] – coefficient for passive pressure for stratum with top on the ordinate Z

Qr_1 [kPa] – maximum horizontal soil resistance for stratum with bottom on the ordinate Z

Qr_2 [kPa] – maximum horizontal soil resistance for stratum with top on the ordinate Z

A [-] – slope of linear function y=Ax + B

B [-] – y-intercept of linear function y=Ax + B

Table **Kx values in nodes**

Z_from [m bgl] – ordinate of the stratum top

Z_to [m bgl] – ordinate of the stratum bottom

Function number – number of functions defining the module of horizontal stiffness of soil between ordinates Z_from and Z_to

A1 [-] – slope of linear function y1=A1x + B1

B1 [-] – y-intercept of linear function y1=A1x + B1

Z2 [m ppt] – ordinate from which soil stiffness is defined by the second linear function y2= A2x + B2

A2 [-] – slope of linear function y2=A2x + B2

B2 [-] – y-intercept of linear function y2=A2x + B2

Z3 [m ppt] – ordinate from which soil stiffness is defined by the third linear function y3= A3x + B3

A3 [-] – slope of linear function y3=A3x + B3

B3 [-] – y-intercept of linear function y3=A3x + B3

Z4 [m ppt] – ordinate from which soil stiffness is defined by the fourth linear function y4= A4x + B4

A4 [-] – slope of linear function y4=A4x + B4

B4 [-] – y-intercept of linear function y4=A4x + B4

Kx [kN/m] – horizontal stiffness of soil in a node

Table **Rgr values in nodes**

Z_from [m bgl] – ordinate of the stratum roof

Z_to [m bgl] – ordinate of the stratum bottom

Function number – number of functions defining the maximum horizontal soil resistance between ordinates Z_from and Z_to

A1 [-] – slope of linear function y1=A1x + B1

B1 [-] – y-intercept of linear function y1=A1x + B1

Z2 [m bgl] – ordinate from which soil resistance is defined by the second linear function y2= A2x + B2

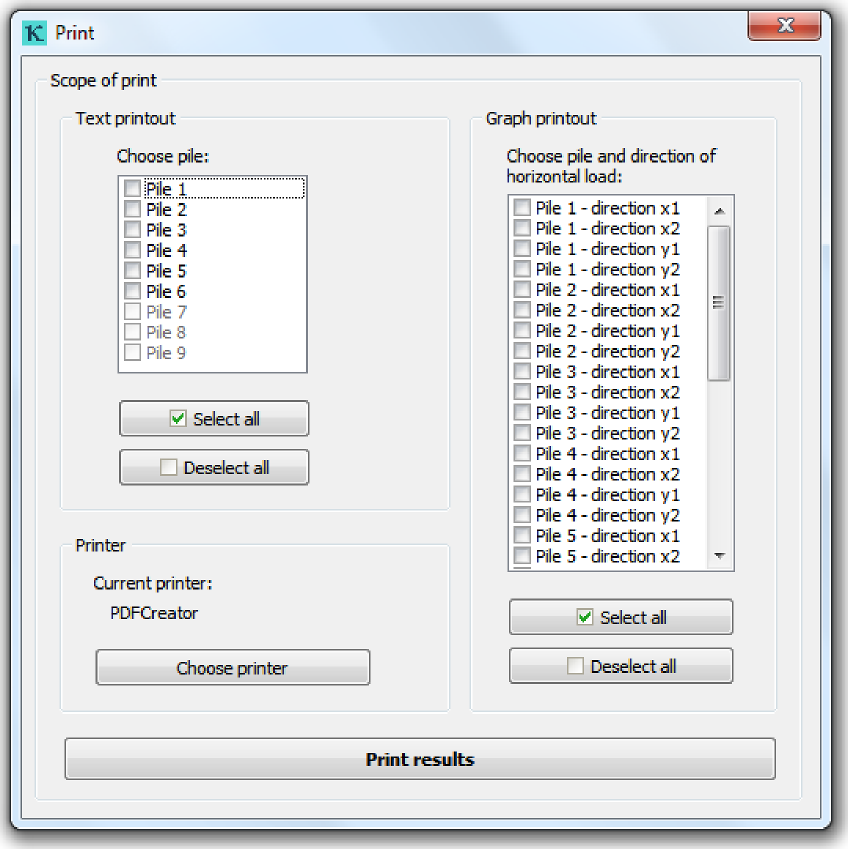
A2 [-] – slope of linear function y2=A2x + B2

B2 [-] – y-intercept of linear function y2=A2x + B2

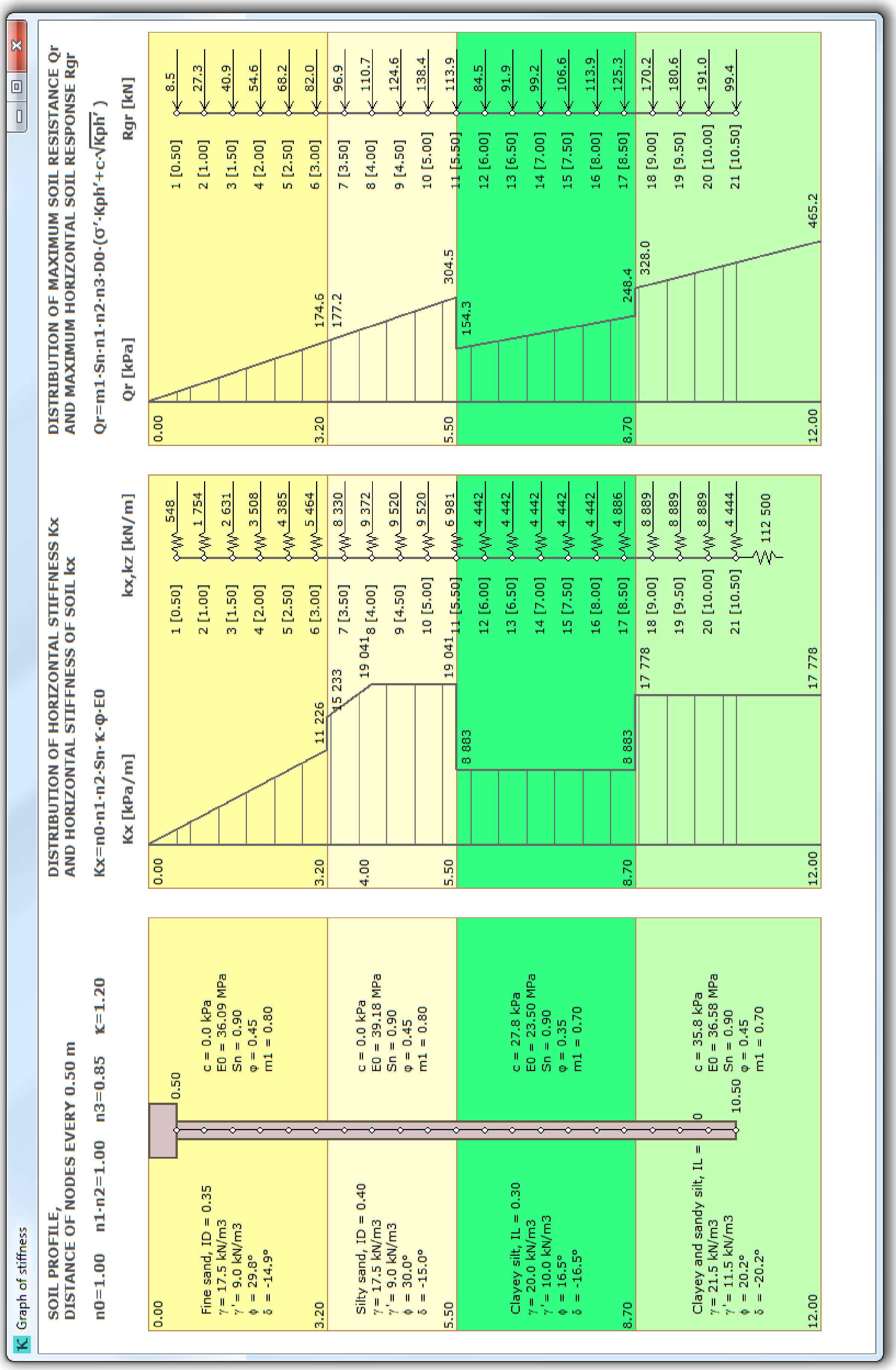
Rgr [kN] – maximum horizontal soil response in a node

Save results – save the performed calculations as an Excel file. Clicking on the button will run the MS Excel and the results will be transported to the excel sheet.

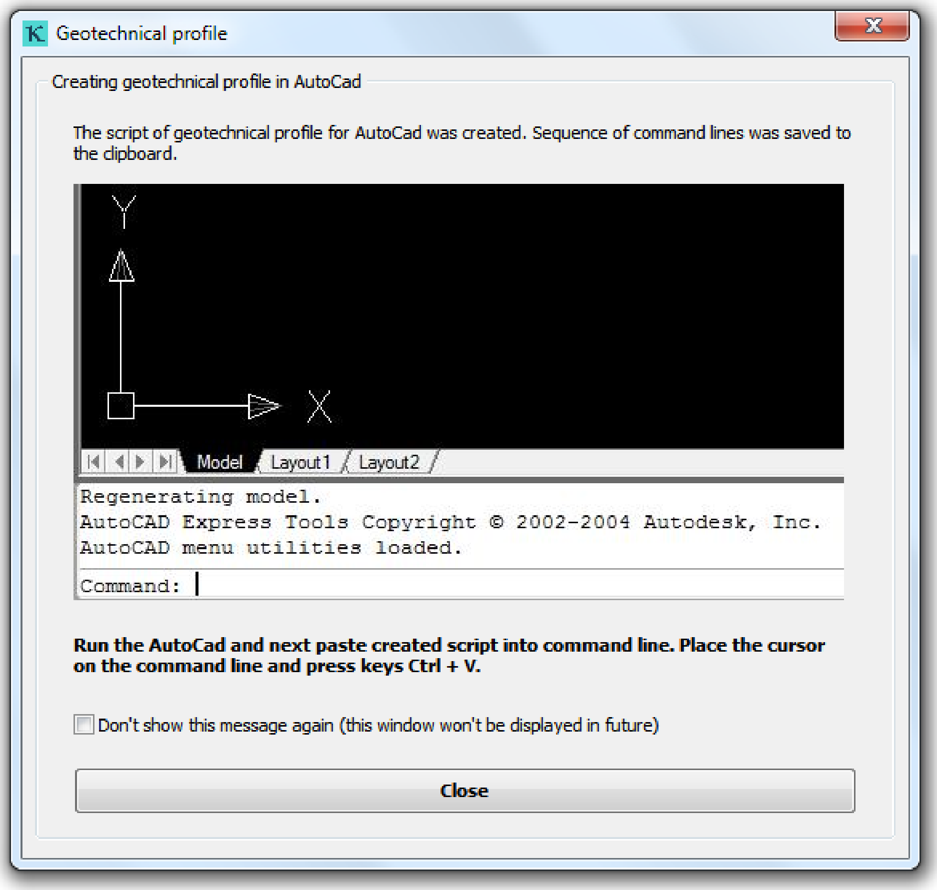
Print results – print the results of the performed calculations. The program allows printing both sections of the calculations i.e. the graphic and text parts for each pile and direction of the horizontal load. It is possible to print only the calculations for selected piles and directions of the horizontal load separately.



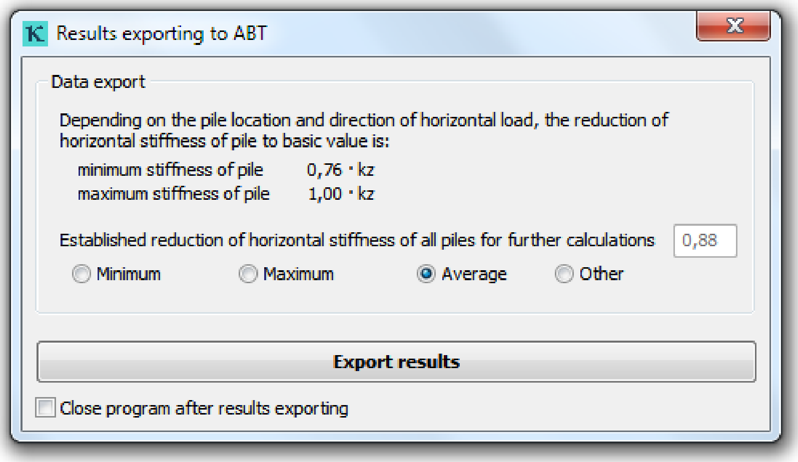
Show graphic – the graphic preview of the performed calculations. It includes graph of module of soil stiffness, maximum soil resistance and the values in particular nodes.


Graph of stiffness
SOIL PROFILE,
DISTANCE OF NODES EVERY 0.50 m
n0=1.00 n1·n2=1.00 n3=0.85 ϰ=1.20
Fine sand, ID = 0.35
γ = 17.5 kN/m3
γ' = 9.0 kN/m3
ϕ = 29.8°
δ = -14.9°
c = 0.0 kPa
E0 = 36.09 MPa
Sn = 0.90
φ = 0.45
m1 = 0.80
Silty sand, ID = 0.40
γ = 17.5 kN/m3
γ' = 9.0 kN/m3
ϕ = 30.0°
δ = -15.0°
c = 0.0 kPa
E0 = 39.18 MPa
Sn = 0.90
φ = 0.45
m1 = 0.80
Clayey silt, IL = 0.30
γ = 20.0 kN/m3
γ' = 10.0 kN/m3
ϕ = 16.5°
δ = -16.5°
c = 27.8 kPa
E0 = 23.50 MPa
Sn = 0.90
φ = 0.35
m1 = 0.70
Clayey and sandy silt, IL = 0
γ = 21.5 kN/m3
γ' = 11.5 kN/m3
ϕ = 20.2°
δ = -20.2°
c = 35.8 kPa
E0 = 36.58 MPa
Sn = 0.90
φ = 0.45
m1 = 0.70
DISTRIBUTION OF HORIZONTAL STIFFNESS Kx
AND HORIZONTAL STIFFNESS OF SOIL kx
Kx=n0·n1·n2·Sn·ϰ·φ·E0
Kx [kPa/m]
kx,kz [kN/m]
DISTRIBUTION OF MAXIMUM SOIL RESISTANCE Qr
AND MAXIMUM HORIZONTAL SOIL RESPONSE Rgr
Qr=m1·Sn·n1·n2·n3·D0·(σ'·Kph'+c·√Kph')
Qr [kPa]
Rgr [kN]

Create soil profile – creates a script (command lines) in the AutoCad. This script is later copied directly to the clipboard. In order to create the soil profile the user needs to run AutoCad, place the cursor on the command line and insert the copied contents (use keys Ctrl + V).



Export to ABT -> – export of data to ABT module. The user needs to establish the reduction of horizontal stiffness for all piles in foundation and next export results to the ABT module.



The author of the program **December 2011r.**

Jakub Roch Kowalski, MSc